Entry by Spinoffs

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Abstract

Entry by spinoffs from incumbent firms is investigated for the laser industry. A model in which spinoffs exploit knowledge from their parents is constructed to explain the types of firms that spawn spinoffs, the market conditions conducive to spinoffs, and the relationship of spinoffs to their parents. The model is tested using detailed data on all laser entrants from the start of the industry through 1994. Our findings support the basic premise of the model that spinoffs inherit knowledge from their parents that shapes their nature at birth, with firms that are more successful spawning more spinoffs. Consistent with the model, spinoffs are more likely in laser submarkets in which knowledge is more embodied in human than physical capital, and spinoffs are more responsive to adverse than favorable market conditions. Implications of our findings for organizational behavior, business strategy, entry and industry evolution, and technological change are discussed.

[Key words: Spinoff, Entry, Firm Capabilities]
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Entry by Spinoffs

Steven Klepper and Sally Sleeper†

I. Introduction

Models and metaphors from biological evolution are increasingly being exploited in the analysis of organizations (Aldrich [1999]), business strategy (Barnett and Burgelman [1996]), and industrial competition (Nelson [1995]). Considerable mileage has been extracted from the fundamental concepts of variation and selection, both of which have clear counterparts in industrial competition. Much less use has been made of a third important aspect of biological theories of evolution, heredity, which involves reproduction and transmission of genes to offspring (Nelson [1995, p. 54]). In this paper, we use the notion of heredity to analyze a distinctive class of industry entrants, spinoffs from incumbent producers, that have a clear parental heritage. Despite the prominence of spinoffs in industries such as semiconductors (Braun and MacDonald [1978, pp. 121-145], Malone [1985]) and disk drives (Chesbrough [1999]), we have little knowledge about why they are more prevalent in some industries than others, the market conditions that favor their formation, and the types of firms that spawn them. To address these questions, we develop and test a model in which spinoffs inherit knowledge from their parents, where knowledge may be thought of as the industrial counterpart to genes (cf. Nelson and Winter [1982, pp. 14-16]).

We use the model to analyze the kinds of firms that are more likely to spawn spinoffs, the market conditions conducive to spinoffs, and the relationship of spinoffs to their parents. We test the model using detailed data we collected on the evolution of one industry, lasers, where spinoffs have been prominent. Using an annual buyers' guide, we identified every producer in the industry from its start through 1994, and using various business directories, patent records, a monthly trade journal, and bibliographic data bases,

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we traced the lineage of every producer. We found that over 15% of the firms, including many of the leading firms in the industry, were spinoffs, which we define as firms started by employees of other laser producers. We assembled annual data on the types of lasers every firm produced, whether and when they were acquired by laser and nonlaser producers, their location, and their background prior to entry, including the types of products and numbers of patents of firms that produced other products prior to lasers. For spinoffs, we also identified the initial type of laser they produced and their main parent, and we assembled information about their relationship to their parents and the initial strategies they pursued. We used our model to organize and interpret the data and we used the data to estimate a series of logit models to test the predictions of the model concerning the firm and market factors conducive to spinoffs.

Our findings provide considerable support for the basic premise of our model that spinoffs inherit knowledge from their parents that shapes their nature at birth. Spinoffs also differ from their parents due to deliberate efforts to differentiate themselves, as the model predicts. Longer-lived firms spawn more spinoffs. They are not only around longer to spawn spinoffs, but they live long enough to attain the most fertile periods for spinoffs, which we interpret as when the firm possesses the most knowledge for spinoffs to draw upon. Consistent with the model, spinoffs are not responsive to conditions favoring entry generally but are discouraged by adverse conditions. They are more likely in submarkets in which competitive knowledge is embodied in human capital, an essential condition in the model for spinoffs to occur. We also find support for various predictions of the model concerning how the pre-entry background of producers, acquisitions, and geographic agglomeration of producers affects the likelihood of spinoffs. Our findings have numerous implications regarding organizational behavior and business strategy, the determinants of entry, and the welfare effects of spinoffs.

The paper is organized as follows. In Section II we review prior work relating to spinoffs. In Section III we present our model and derive various predictions from it. In Section IV we review the evolution of the laser industry. In Section V we describe our data sources and provide an overview of the firms that spawned spinoffs, the timing of their spinoffs, and the relationship between spinoffs and their parents. In Section VI we estimate three logit models concerning the firm and market characteristics influencing the incidence and timing of spinoffs. In Section VII we discuss the implications of our findings and offer concluding remarks.

II. Prior Work on Spinoffs

Firm startups in technical industries like lasers have been analyzed in a number of studies. Few studies, however, focus narrowly on startups by employees of incumbent firms—i.e., spinoffs. Garvin [1983] discusses the findings of many of the studies of technical startups, which he uses to reflect on the generic character of spinoffs across a wide range of industries. In an unpublished paper, Brittain and Freeman [1986] estimate a hazard model of the likelihood of spinoffs from semiconductor firms in Silicon Valley in the period 1955-1981. Coupled with the broader literature on technical startups, the studies of Garvin and Brittain and Freeman present various results and conjectures that provide a useful backdrop for our model.

Technical startups are generally founded by well-educated and experienced employees of comparable types of firms (Cooper [1984, 1986]). As Garvin notes, many studies of technical startups frame their analyses by examining the conditions that induce employees to leave secure positions to start their own firms. A common theme is that spinoffs occur when employees are frustrated with their employer. The frustration is often related to innovation. Sometimes employees want to pursue innovative ideas their employers are not willing to undertake. Relatedly, sometimes employees feel they have better insights than their employer about how to capitalize on an innovation developed by their employer or elsewhere. To the extent innovation is the impetus for startups, conditions favorable to innovation and sharing of information are often identified as important determinants of startups. These include high R&D spending as a percentage of sales, liberal licensing of technology and norms favoring information exchange, and geographic agglomeration of producers facilitating the diffusion of information and the formation of management teams. These conditions are characteristic of electronics industries, which explains the preponderance of studies of startups in the semiconductor and other electronics industries.

Garvin notes that spinoffs are common in many nontechnical industries such as consulting and music. Therefore in theorizing about spinoffs he emphasizes their generic character. He argues that many of the factors connected to innovation that are conjectured as determinants of technical startups are really just determinants of entry, and he focuses his analysis on the factors favoring spinoffs over other kinds of entry. Two generic industry factors are identified as conducive to spinoffs. One is when the knowledge firms exploit is more embodied in skilled labor than physical capital. The other is when no dominant design exists for an industry's product. The former condition facilitates the transfer of knowledge to spinoffs through their founders. The latter bears on the opportunities available to spinoffs. When there is no dominant product design, the rate of introduction of new product variants is high. This opens up new niches, which are difficult for industry outsiders to learn about on a timely basis, thus providing distinctive opportunities for employees of incumbent firms to exploit.[1] Narrow niches also favor spinoffs by reducing the organizational challenges facing new firms. Based on the logic of the product life cycle (Utterback and Abermathy [1975], Klepper [1996]), the conditions favoring spinoffs are expected to be satisfied to a greater degree in younger, less mature industries, although Garvin recognizes that industries proceed through the product life cycle at different rates. Garvin presents anecdotal evidence from a number of industries to support his arguments.

In their study of semiconductor spinoffs in Silicon Valley, Brittain and Freeman [1986] also consider the market conditions favorable to spinoffs, but they focus their statistical analysis on the conditions in incumbent (semiconductor) firms that are conducive to spinoffs. Situational factors such as unemployment, retirement, and forced resignation have been found to push individuals into self employment (Carroll [1993]). Brittain and Freeman conjecture that analogous circumstances within incumbent firms contribute to spinoffs, presumably by affecting the prospects of employees. They find support for three such factors within firms: a new CEO hired from outside the industry, acquisition by a firm outside the industry,[2] and slowed growth blocking upward mobility

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[1] Implicit in this view is that incumbent producers are not well suited to pursue these opportunities (cf. Mitchell [1998]).

[2] Mitton [1990] similarly finds that acquisitions affect the incidence of spinoffs (and other kinds of startups) from biotechnology firms.

of employees. They conjecture that conditions within the firm bearing on knowledge also influence spinoffs. They find the likelihood of spinoffs greater from firms that produced a wider range of semiconductor products, entered first in one or more of their product groups, and produced primarily semiconductors. They interpret the first two factors as influencing the amount of knowledge employees have to draw upon to start their own firm, where first entrants are assumed to be more innovative and thus more knowledgeable. Firms whose primary business is not semiconductors were assumed to rotate their employees across different businesses, limiting their access to the knowledge needed to start their own semiconductor firms. They also considered the influence on spinoffs of various market conditions, such as the number of firms, recent entry and exit rates, and industry sales growth. These factors did not consistently have the expected effects, though as a group they had a significant impact on the likelihood of spinoffs.

Certain themes emerge from the Garvin and Brittain and Freeman studies that help frame our analysis. First, spinoffs are seen as exploiting knowledge from the firms that employed their founders, which are commonly described as their "parents." The knowledge may be associated with innovation, but it also may be more general knowledge about market or technical opportunities. Thus, industry conditions bearing on the amount and kind of knowledge firms acquire and the accessibility of the knowledge to employees all influence the likelihood of spinoffs. Second, spinoffs are thought to occur when employees perceive their firms are not taking full advantage of "niche" opportunities that either resulted from the firm's efforts or originated outside the firm. Industry conditions favorable to the creation of such niches are thus conducive to spinoffs. So are situations that may cause firms to miss opportunities, such as control changes involving outsiders to the industry. Third, spinoffs are a distinctive form of entry that is not responsive to market conditions in the same way as other kinds of entry. Last, it is implicitly assumed that spinoffs closely resemble their parents. While no direct evidence is presented to support this characterization, it resonates strongly with the findings of studies of startups in technical industries like lasers. Such startups tend to locate close to their parents and to pursue similar market and technological strategies to their parents (Cooper [1971, 1984, 1986], Feeser and Willard [1989], Roberts [1991, pp. 104-106]).

III. Model of Spinoffs

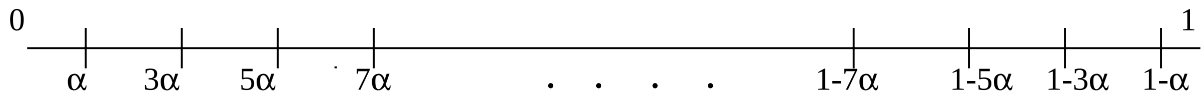
The model is a variant of one employed by Prescott and Visscher [1977] to analyze product differentiation within an industry. It is assumed that many different variants of an industry's product can be produced, and buyers have different preferences for the alternative variants. To offer for sale any particular variant, sellers must invest in know-how. This investment, which is a sunk cost of entry, limits the number of variants that can be profitably offered. To allow for spinoffs, it is assumed that some firms may have employees that can exploit the firm's know-how to lower the cost of starting their own firm. This provides a distinctive rationale for spinoffs. The model yields a number of testable implications regarding the nature of spinoffs, the kinds of firms that are more likely to generate spinoffs, and the market conditions conducive to spinoffs. It also provides a unified and refined basis for past conjectures and findings.

We begin by laying out Prescott and Visscher's model. Different variants of an industry's product are represented by points on the [0,1] interval. Buyers purchase one unit of the variant that maximizes their utility. Each buyer has a preferred variant corresponding to a point in [0,1]. If all sellers charge the same price, buyers purchase the variant located closest to their preferred point. Buyers' preferred points are uniformly distributed on [0,1], and the total number of buyers is known.

Sellers can offer a variant for sale by choosing a point on [0,1] and investing in the know-how needed to produce and market their variant. Denote the cost of this investment as c. All firms are assumed to charge the same price for their variants. A firm's gross profits before subtracting the cost of its initial investment in know-how is then determined by its market share. Let α denote the expected market share firms need to generate sufficient gross profits to cover their entry cost c given the total number of buyers and the price charged by sellers.

Prescott and Visscher abstract from the nature of potential entrants by assuming a queue of potential entrants that enter in a given order. Each entrant decides whether to produce a new variant given the variants chosen by prior entrants. While each entrant chooses a single variant, some may enter at multiple times in the entry queue. Thus, some firms occupy multiple locations, each with its own market—i.e., they are diversified within the industry. Firms enter as long as they can capture an expected market share (infinitesimally) greater than α. The order of entry and the number of times firms enter in the queue can be thought of as being determined by the backgrounds of firms prior to entry, which condition when they learn about opportunities in the industry and the variants they are capable of offering.

Entrants are assumed to be foresighted in that they form conjectures about the profit-maximizing choices future entrants will make given past choices, including their own. Prescott and Visscher establish the existence of an equilibrium in which the actual location choices of entrants are consistent with their conjectures. The locations chosen are:



with the first two entrants choosing the locations α and 1-α, the next two choosing the locations 3α and 1-3α, and so forth.

With buyer preferences uniformly distributed on [0,1] and firms charging the same price, each firm captures half the market between itself and each of its neighbors. Thus, these locations enable firms to capture a market share of α on either side, for a total market share of 2α. No matter where additional firms entered, they could not capture a market share greater than α, whereas they could if firms were located further apart. Therefore, the best firms could do is to locate 2α apart, which they recognize in forming their conjectures about the choices of future entrants. If 1/2α is not an integer, two or three firms will end up with market shares less than 2α while all the others will have market shares equal to 2α. To minimize their chances of ending up with a market share less than 2α, the first two entrants locate at α and 1-α, guaranteeing themselves a market share of α on one side, and successive entrants occupy positions 2α away from the two prior entrants for the same reason.

We generalize Prescott and Visscher's model by allowing each firm the option of exploiting its know-how to develop a variant of its product at a cost less than c. This implies it will need a market share less than α to cover the costs of an additional variant.

Specifically, if a firm's product is located at d and it sells to buyers in the interval (d-α, d+α), it can use its know-how to develop another product variant located in (d-α, d+α) at a cost less than c. Let α_s denote the market share the firm needs to cover the costs of its additional variant, where $.5\alpha<\alpha_s<\alpha$. To keep the exposition simple, we set α_s equal to $.75\alpha$. Furthermore, we assume that if a firm has employees with access to its know-how that have the requisite organizational skills, they have same opportunity as the firm to develop a variant of the firm's product in their own firm. Such a firm, which we call a spinoff, would be profitable as long as it captured a market share of $\alpha_s=.75\alpha$. We assume that only some firms have employees capable of starting a spinoff. Firms know the probability of having such employees, but no firm knows if any of its employees has the requisite capabilities. We assume this precludes the feasibility of firms contracting with their employees not to start their own firms.

To analyze where entrants would locate and what variants of their products they and their spinoffs might offer, we make the following simplifying assumptions. All entry occurs first, which determines each firm's initial market. Entrants then decide whether to produce variants of their products, and then employees decide whether to start their own firms. This is consistent with a gestation period required for a firm's know-how to be exploited, with the gestation longest for spinoffs. A firm can counter a spinoff by developing a variant of its product anywhere in its original market area. It can only threaten actions, though, that would be profitable at the time they could be undertaken. Firms continue to recognize the maximum distance they can locate from their neighbor without inducing entry and they enter from the extreme optimal locations inward, which is consistent with the equilibrium established.

Our objective is to establish conditions under which the equilibrium set of locations is such that some spinoffs occur. We show that this will be the case as long as the fraction of firms that have employees capable of starting spinoffs is sufficiently low. If this holds, we show that firms will continue to locate 2α apart, no firm will develop a variant of its product, but some firms will spawn spinoffs.

Consider first the maximum distance between two firms that will not induce entry. It turns out to be the same as in Prescott and Visscher's model--2α. To see this, suppose two neighbors are located $2\alpha+\delta$ apart, where $0<\delta<\alpha$. If a third firm entered at the midpoint between them, it would capture a market share of $.5\alpha+.25\delta$ on either side for a total market share of $\alpha+.5\delta$. Furthermore, no spinoff (from the entrant or its two neighbors) would find it profitable to enter anywhere between the original two neighbors because the maximum market share it could capture would be $.5\alpha+.25\delta<.75\alpha$. Similarly, neither of the entrant's two neighbors would find it profitable to produce a variant of its product. Therefore, entry would be profitable. If $\delta\geq\alpha$ and the firms were located at least 3α apart, an entrant could locate to preclude a spinoff on one, but not both, of its sides. However, it is easy to show that as long as the probability of a spinoff is sufficiently small, the prospect of a spinoff later capturing some of its market share would not compromise the profitability of the entrant. Therefore, firms cannot locate more than 2α apart without inducing entry, as in Prescott and Visscher's model.

The only change of (limited) consequence from Prescott and Visscher's model concerning entry is that the first two firms could locate further from the endpoints than α without inducing entry because of the possibility of a spinoff subsequently capturing some of an entrant's market share.[3] This makes these locations more attractive than the others, reinforcing their attractiveness to the first two firms. Thus, one possible outcome of the entry stage of the model is that the first two firms locate as far from the endpoints as is possible without inducing entry, the next two locate 2α from the first two, the next two locate 2α from the prior two entrants, and so forth. While firms cannot locate further apart than this, they might want to locate closer, which is considered below.

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[3] These locations are bounded, however, at 1.25α from the endpoints. To see this, note that if the first firm located beyond this, say at $1.25\alpha + \delta$, $0<\delta<\alpha$, then another firm could enter at $.75\alpha$, capturing a market share greater than α while leaving no room for a profitable spinoff or an additional product variant from the first firm. If the initial firm located even further from the endpoint (i.e., at 2.25α or beyond), an entrant at $.75\alpha$ would not be able to prevent a spinoff from subsequently entering, but as long as the probability of a spinoff were sufficiently small, this would not compromise the entrant's profitability.

If firms entered at these locations and subsequently did not offer additional variants of their products, some spinoffs would enter. To see this, consider a firm located at d with neighbors at d-2α and d+2α. Suppose the firm had employees capable of starting a spinoff. If the spinoff entered at the extreme of its parent's market area, say at d-α, it would capture a market share of α. Furthermore, it would not be profitable for either firm at d-2α or d to offer a variant of its product or for a subsequent spinoff to enter between d-2α and d because the maximum market share each could capture is .5α. Therefore, the spinoff would be profitable, and firms with capable employees would spawn spinoffs. Note that a spinoff could locate anywhere in its parent's market area and capture a market share of α. It also need not locate at the extreme of its parent's market area to retain subsequently its market share. It could not, however, locate next to its parent, for then it would be profitable for its parent to retaliate by offering a variant of its product on the other side of its spinoff, reducing the spinoff's market share. Thus, spinoffs will differentiate their products from those of their parents.

To complete the proof that firms will locate 2α apart and spinoffs would enter, it must be shown that it would not be profitable for two neighbors to take actions to preempt spinoffs between them. They could achieve this either by initially locating 1.5α rather than 2α apart, or by one of the firms locating a variant of its product between them near the extreme of its market. If neither of these actions was taken and a spinoff entered between the two firms, the market share each firm would lose would depend on the location of the spinoff, but each firm's expected market share loss would be .5α. Let p denote the probability of a spinoff entering between the firms if they were located 2α apart. If they instead located 1.5α apart, each firm would give up a market share between them of .25α and would gain an expected market share from deterring a spinoff between them of .5α times p. The gain would exceed the cost if spinoffs were a sure thing, but if p is less than .5 then $.5\alpha p<.25\alpha$ and it would not pay for firms to locate 1.5α apart to deter spinoffs.[4] Alternatively, if either firm located a variant of its product between itself and its neighbor, it could capture a maximum market share from its neighbor of .5α and

[4] The condition $.5\alpha p<.25\alpha$ also insures that firms located 2α apart are profitable.

would save the expected market share loss to a spinoff of $.5\alpha p$. The former gain alone would never be sufficient to cover the costs of the second variant, nor would the total gain if $.5\alpha+.5\alpha p<.75\alpha$.[5] Rearranging, this is the same condition as above. More generally, if the probability of a spinoff from any firm is nonnegligible but sufficiently small, then it would never be profitable for firms to preempt spinoffs, and some spinoff entry would be expected.

The model involves many simplifications, but it incorporates three basic ideas that underlie the occurrence of spinoffs. First, nonspinoff entry does not exhaust the possibilities for spinoffs because spinoffs can exploit the know-how of their parents to enter at a lower cost than nonspinoff entrants. Second, even though parents can offer the same product variants as their spinoffs, this is less profitable to them than their spinoffs. They would cannibalize some of their market if they offered a variant of their product, whereas spinoffs do not have a market to cannibalize. Last, spinoffs are not a sure thing. If they were, it would pay parents to preempt them. But as long as the probability of spinoffs is sufficiently small, potential parents are better off not acting preemptively and gambling that neither they nor their neighbors have employees capable of starting their own firms.

We can now state a series of hypotheses that either follow directly from the model or follow with a little embellishment. These hypotheses help put prior findings and conjectures in perspective and provide testable predictions.

Hypothesis 1: Spinoffs capture smaller market shares than nonspinoff entrants—generally market shares half those of nonspinoff entrants. This accords with Garvin's association of spinoffs with niches in the market. It follows, however, without resorting to Garvin's notion of employees of incumbent firms being better positioned to spot new niches. In the model, spinoffs service the same basic markets as their parents. They have smaller market shares than nonspinoffs because they have access to the know-how of

[5] This condition also insures that the expected joint market share gain to the two neighbors of αp would not exceed the market share of $.75\alpha$ needed to cover the cost to either firm of a variant of its product.

their parents, which makes it possible to service profitably smaller markets than nonspinoff entrants.

Hypothesis 2: Because spinoffs do not have a market to cannibalize, they find it profitable to produce a variant of their parent's product that their parents do not find profitable (assuming the probability of spinoffs is sufficiently low). This would help explain the common observation that spinoffs occur when employees are frustrated with their parents' unwillingness to pursue their ideas. Normally this is interpreted as a sign of some kind of bureaucratic inertia among incumbent producers, but the model indicates that it may be the result of firms and their employees having different incentives to develop variants of the firms' products.

Hypothesis 3: Spinoffs draw upon their parents' know-how to produce products similar to, but differentiated from, their parents. Laser firms tend to specialize in the production of particular lasers. This suggests that spinoffs will initially produce the same types of lasers as their parents, while at the same time attempting to differentiate their lasers from those of their parents. Spinoffs should not threaten the viability of their parents' related products—even if their parents' entry costs were not already sunk, a spinoff takes away less than half of its parent's total market share, leaving its parent with sufficient market share to more than cover its entry costs. So parents should continue to produce the types of lasers initially produced by their spinoffs.

Hypothesis 4: The key to spinoffs in the model is firms investing in know-how and employees having access to the know-how. Know-how is typically associated with a firm's R&D and marketing efforts. This suggests that the founders of spinoffs would be involved in their parents' R&D or marketing efforts. It also suggests spinoffs would occur to a greater degree in more R&D and/or marketing intensive industries and in industries where the R&D and marketing knowledge is embodied in the firm's employees rather than physical capital. The first condition certainly fits lasers. It also fits electronics industries, which can explain the preoccupation in the literature with spinoffs in electronics. At the same time, it allows for spinoffs in marketing intensive industries, consistent with Garvin's observation that spinoffs are not restricted to high-tech industries. The second condition is consistent with Garvin's emphasis on the product life cycle (plc). Certain lasers have progressed further along the plc in terms of having a more stabilized design and more attention being devoted to improving the production process. If this contributes to firm know-how becoming more embodied in physical than human capital, as Garvin conjectured, these lasers should experience a decline over time in their rate of spinoffs.

Hypothesis 5: Each location occupied by a firm is an independent source of spinoffs. Hence more diversified firms within an industry should generate more spinoffs. This accords with Brittain and Freeman's finding that semiconductor firms with products in more groups had more spinoffs. Thus, all else equal, firms producing a greater number of distinct types of lasers should generate more spinoffs. The probability of a spinoff from one location, however, should be independent of the number of other distinct locations a firm occupies. Consequently, the probability of a firm spawning a spinoff initially producing a particular laser should depend only on the firm's experience producing that laser.

Hypothesis 6: Firms vary considerably in terms of the success of their R&D and marketing efforts. More successful firms might be expected to generate greater know-how, which in turn could lower the organizational skills needed by employees profitably to start their own firms. This suggests more innovative firms will spawn more spinoffs, which is consistent with Brittain and Freeman's interpretation of their finding that semiconductor firms that were first entrants in their product groups had more spinoffs. More successful firms also generally survive longer. This suggests that the likelihood of a firm spawning a spinoff initially producing a particular laser should be greater the longer the firm produced the laser. We might also expect this likelihood to vary over the firm's lifetime producing the laser. Studies of startups indicate they typically begin with meager resources and minimal skills, and if successful they invest in R&D and marketing to increase their know-how (Braden [1977, pp. 27-29], Roberts [1991, pp. 166-182], Bhide [2000, pp. 29-68, 207-259]). This might well cause the probability of a firm spawning a spinoff initially producing a particular laser to rise as the firm expanded its R&D and marketing investment in the laser. More speculatively, eventually the opposite pattern might set in if, as has been found (cf. Miller and Friesen [1984], Kazanjian and Drazin [1989]), (successful) firms increasingly turn their attention to lowering cost and setting up functional divisions that may limit employee access to key information. This suggests that the likelihood of firms spawning spinoffs initially producing a particular laser may be a nonmonotonic function of the number of years they produce the laser.

Hypothesis 7: Growth in demand will lower the expected market share entrants and spinoffs need to be profitable. In the case of entrants, this will lower the market share they need to enter below α. With firms located 2α apart, demand growth would then lead to entry when none was profitable previously. Alternatively, spinoff entry does not require demand growth to be profitable—it depends primarily on firms having valuable know-how and employees with the requisite organizational skills having access to the know-how. This suggests that demand growth will have a greater effect on nonspinoff than spinoff entry. Alternatively, suppose demand declines, as has occurred for some types of lasers. Nonspinoff entry will continue to be unprofitable, and spinoff entry will cease being profitable as well if the market share spinoffs need to be profitable rises above α. This suggests an asymmetric response of spinoffs to market conditions, with conditions favorable to entry having less effect than conditions adverse to entry on the rate of spinoffs. This may help explain Brittain and Freeman's finding that the rate of spinoffs among semiconductor firms was not related in the expected way to market conditions such as the overall rate of entry and the growth in semiconductor sales.

The model can also be used to address Brittain and Freeman's findings concerning the effect of control changes and nonsemiconductor production on the spinoff rate, and conjectures about the high rate of spinoffs in geographically agglomerated industries. We state three hypotheses that follow from the model under certain conditions.

Hypothesis 8: If control changes lead firms to change their product positions, they could expand the market for spinoffs. This could raise the probability of a spinoff, which is consistent with Brittain and Freeman's findings concerning the effect of control changes on spinoffs. Their findings pertained only to control changes involving outsiders to the industry, but in lasers many control changes involved acquisitions of one laser firm by another. If acquisitions lead firms to reposition their product offerings, we would expect acquisitions of any kind to raise the likelihood of firms spawning spinoffs.

Hypothesis 9: If agglomerations facilitate the formation of founding and initial management teams, they could enhance the chances of employees in a firm being able to put together a spinoff. This suggests that the rate of spinoffs in laser firms should be related to the density of firms located in their geographic region. This argument assumes spinoffs generally locate in the same region as their parents and some spinoffs draw on multiple firms in their region to form their founding and initial management teams, which accords with findings on technical startups (Cooper [1970, 1984], Mitton [1990]). We will explore each of these links in lasers.

Hypothesis 10: Any background characteristic of a firm bearing on its ability to generate know-how or that affects the access employees have to the firm's know-how will affect the firm's rate of spinoffs. Thus, if diversified laser firms limit the accessibility of employees to their know-how by rotating them across different businesses, as Brittain and Freeman conjectured for semiconductors firms, then they should have a lower rate of spinoffs.

IV. Evolution of the Laser Industry[6]

The theory behind the laser is based on the theory of quantum mechanics. In 1916, Einstein postulated that bombarding an electron in an excited state with a photon of proper energy could induce spontaneous emission of another photon of identical energy. He called this stimulated emission, which is the basic idea behind the laser. Stimulated emission rarely occurs naturally. It requires shifting or inverting a population of electrons from a low to an excited state, called a population inversion.

Charles Townes, a Columbia University physicist, first achieved a population inversion in 1954 by passing a beam of ammonia molecules through an electric field. The novelty of his approach was the incorporation of an oscillator cavity to reflect the emitted photons, leading to further stimulated emission of photons. Townes' device, known as the maser (Microwave Amplification by Stimulated Emission of Radiation), generated invisible microwaves with wavelength 10,000 times longer than visible light. The breakthrough to the laser (Light Amplification by Stimulated Emission of Radiation)

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[6] This section draws primarily on Bromberg [1991], Hecht [1992], Harbison and Nahory [1997], and especially the monthly issues from 1965-1994 of the trade journal *Laser Focus*.

occurred in 1958 when Townes and Arthur Schalow of Bell Labs proposed enclosing the cavity for stimulated emission in a pair of reflecting mirrors that would reflect only photons of energy corresponding to a selected wavelength in the visible light range. This would create a buildup of reflected photons, a small part of which would be allowed to escape through a small hole in one of the mirrors, yielding a beam of light of a single wavelength (monochromatic), with all waves in phase (coherent), and tightly collimated to minimize the divergence of the beam. These qualities, along with the great potential intensity of the light, are the distinguishing features of laser light that makes it useful for a wide range of applications.

The first operating laser was developed in 1960 by Theodore Maiman of Hughes Laboratories using a doped synthetic ruby crystal as the laser medium. Subsequently, a wide range of materials have been made to "lase," including other doped solid-state crystals, various gases, semiconductor materials, and chemical dyes. Depending on the material and properties of the laser, they produce light of different wavelengths spanning the visible light range (and beyond) of the electromagnetic spectrum. We distinguish nine different types of lasers that tend to draw on different types of expertise and service different applications. They include solid-state, semiconductor, chemical dye, and six types of gas lasers: helium-neon (HeNe), carbon dioxide (CO2), ion, excimer, helium-cadmium (HeCd), and a catchall category of all other gas lasers.

Early commercial lasers were used primarily for research and military sales exceeded commercial sales, but over time improvements in commercial lasers have reversed this balance and the number of commercial laser producers has steadily grown. In the top part of Figures 1-7 we present the annual number of commercial laser producers, nonspinoff entries, and exits for the seven most significant of our nine laser types. These series were computed from listings of laser producers by type of laser in the annual Buyers' Guide published by *Laser Focus*. We matched consecutive listings, adjusting for name and address changes and treating firms acquired by nonlaser companies as continuing producers and firms acquired by laser producers as censored exits.[7] We aggregated the listings into our nine categories based primarily on Hecht [1992]. While the number of producers generally increased over time for all the laser types, in recent years the number of HeNe, CO2, and dye producers has declined due to challenges from semiconductor and solid state lasers.

Most of the laser types have numerous varieties that are used for different applications and are produced in modest volumes by different firms. There are two noteworthy exceptions to this pattern. HeNe lasers are inexpensive, low-power lasers whose design has stabilized over time. They are produced in large volumes and competition has focused on their price, with a great deal of effort devoted to improving the production process of HeNe lasers. Ion lasers, especially argon ion lasers, have also developed large-volume industrial applications. Similar to HeNe lasers, the design of industrial ion lasers has stabilized and competition has focused on price, which has also contributed to considerable effort being devoted to improving the production process.[8]

No concentration data are reported separately for laser devices, but the laser market has been very competitive, as reflected in the rise in the number of U.S. producers. At one point, the top two U.S. firms, Spectra Physics and Coherent, were estimated to account for 30% of worldwide sales (Laser Focus [1974, p. 20]), but their market share appears to have declined considerably in recent years as inroads have been made by Japanese producers, European firms, and more recent U.S. entrants. The U.S. industry has been subject to a great deal of turnover of producers, with only 2 of the 24 pre-1965 entrants and 7 of the 94 pre-1970 entrants still in the industry in 1994. Firms

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[7] The Buyers' Guides have been published since 1966. Data for earlier years are based on Bromberg [1991], Semiconductor Products [1963], and *Thomas' Register of American Manufacturers*, 1963-1966. Acquisitions were identified based on a search of the monthly issues of *Laser Focus*.

[8] Short-wave semiconductor lasers, which are heavily used in CD players, printers, and more recently bar-code scanners, have also followed a similar evolution to HeNe and ion lasers. This is not especially relevant for our purposes, though, because these lasers have been dominated by Japanese firms, and U.S. producers of semiconductor lasers have specialized in long-wave semiconductor lasers used primarily in communications.

tend to specialize by type of laser, but a small number produce lasers in many categories. Of the 465 firms we analyze, 55% produced only 1 laser, 20% 2 lasers, 23% 3-6 lasers, and 2% 7-9 lasers, with the average equal to 2. Entrants located through the U.S., but especially in four areas: Northern California around Silicon Valley, Southern California around Los Angeles, and in metropolitan New York and Boston, which respectively account for 15%, 13%, 7%, and 7% of the entrants.

V. Overview

In this section, we discuss our data sources and provide an overview of the firms that spawned spinoffs, the timing of their spinoffs, and the relationship of the spinoffs to their parents.

We attempted to trace the lineage of every U.S. entrant listed in the annual Buyers' Guides through 1994. Using various business directories,[9] U.S. Patent Office records, *Laser Focus* Buyers' Guide listings of laser component and system producers, and the Web, we identified 293 "preexisting" firms that produced other products at least four years before they produced lasers. For each firm, we determined its founding year, the number of patents it was issued in the five years before it produced lasers, and (when available) the products it produced in the three years before lasers. We used reports in *Laser Focus*, publication searches for the firms' initial principals, and searches of the Web to determine the origin of the other 193 firms. Seventy-nine firms were identified as having one or more founders or principals that had been employed by a laser firm,[10] and

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[9] These included *Corp Tech*, *The Corporate Directory of United States Public Companies*, *The International Directory of Corporate Affiliations*, *The Million Dollar Directory*, and *Moody's*.

[10] Sixty-four of the firms were identified based on a report in *Laser Focus*, with the other 15 identified through publication searches. A few of the latter were suspicious based on little overlap between spinoff and parent, but we included them nonetheless. We also included four spinoffs whose founder(s) worked for another firm that researched or produced lasers for the military or itself but did not initiate commercial production of

these constitute our sample of spinoffs.[11] For each spinoff, we determined its main parent based on where its founders had been employed[12] and its initial laser based on the first and/or longest laser it produced.[13] We also identified the prior positions of many of the founders. For most of the spinoffs and their parents, we found information on the products they produced and markets they serviced in reports in *Laser Focus* and in the product specifications in the Buyers' Guides. This was revealing for roughly 30 of the spinoffs about the initial product and market strategies they employed relative to their parents. In our search through reports in *Laser Focus*, we also recorded any information we found about parents that sued their spinoffs for patent infringement, sold or licensed inputs or technology to their spinoffs, and researched and/or produced for themselves or the military (but not commercially) a laser initially produced by their spinoff.

The data on parents and their spinoffs are presented in Figures 1-7 for the seven main types of lasers and in Figure 8 for the other two laser types. For each type of laser, each parent that spawned a spinoff initially producing the laser type has a separate entry. The parents are ordered based on the timing of their spinoffs, with the name of the parent on the right followed by a number from 1 to 10 indicating the region where the parent entered and an asterisk if the parent itself was a spinoff. For example, Figure 1 indicates that Varian, which entered in region 9 (Northern California), was the first of eight firms

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lasers until after the spinoff. We conducted the statistical analysis with and without these firms, which had little impact on our estimates.

[11] Among the remainder, 44 had founders or principals employed by universities and government labs, 25 had founders or principals employed by nonlaser firms, and 24 were startups whose founders and principals we could not trace. We could not trace at all the remaining 21 firms, and they were excluded from the analysis.

[12] For the 12 firms with multiple founders from different firms, we based the identification of its parent on the number of founders from each firm and reports in *Laser Focus* on the influence of the various founders on the firm.

[13] For the small number of spinoffs that produced multiple lasers over their entire (generally short) lifetime, we chose as their initial laser the most important one based on reports in *Laser Focus* and listings in the Buyers' Guides.

to spawn a spinoff producing HeNe lasers. The entry for each parent spans the years it produced any laser, with the horizontal axis of the top figure used as the time line. A box indicates the years the parent produced the laser type initially produced by its spinoff, with the box shaded for parents that were themselves spinoffs that produced the laser type initially. The ovals indicate the year of the parent's spinoffs. The codes C, S, and P indicate if a parent sold or licensed inputs or technology to the spinoff (C), sued the spinoff for infringement (S), or researched and/or produced for itself or the military (but not commercially) the spinoff's initial laser when the spinoff entered (P). An A to the right of the parent's entry indicates it exited by being acquired by another laser firm and an N indicates a year in which the parent was acquired by a nonlaser firm.

The eight figures provide a detailed overview about the firms spawning spinoffs, the timing of their spinoffs, and the relationship of the parents to their spinoffs. Consider first the relationship between the spinoffs and parents in terms of the lasers they produced. For 66 of the 79 spinoffs, the box for the parent indicates that the parent produced the spinoff's initial laser at or before the spinoff's entry. The overlap is impressive in light of the fact that 55% of the firms produced only one of the nine types of lasers (the average number per firm was two) and only nine of the spinoffs were aided by their parents as reflected in the C codes. Furthermore, in the other 13 spinoffs, the P code for seven of them indicates that while the parent did not commercially produce the spinoff's initial laser at the time of its entry, it had experience with the laser before the entry of the spinoff. Thus, in all but six of the spinoffs, the spinoff had relevant knowledge from its parent to draw upon, as portrayed in the model (Hypothesis 3).[14] Moreover, nearly all the founders worked in technical, marketing, or high-level management positions with access to their parents' R&D and marketing knowledge, as predicted (Hypothesis 4).

In 51 of the 79 spinoffs, the parent produced the spinoff's initial laser at the time the spinoff entered. In 41 of these cases, the parent either continued to produce the laser

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[14] This included not only technical but also market knowledge, as many of the spinoffs not only produced the same types of lasers as their parents but also serviced similar specialized markets to their parents.

for at least three years, sold or licensed its technology to its spinoff, or was censored (i.e., was acquired by another laser producer or continued to produce the laser through 1994). Thus, consistent with Hypothesis 3, in only 10 instances is there any suggestion of the spinoff threatening the viability of the market for the parent's related laser. Moreover, in half of these 10 cases the spinoff produced its initial laser for three or less years, suggesting the parent's market may not have been viable even without the spinoff.

The information we found for approximately 30 of the spinoffs concerning their initial strategies relative to their parents provides further insight into why the spinoffs do not appear to have been much threat to their parents. Consistent with the model (Hypothesis 3), the spinoffs attempted to differentiate their products from their parents at their outset. About a third of the 30 spinoffs intended to produce a custom variant or do contract research in their parent's type of laser. Another third intended to produce the same type of laser as their parent but with either a higher or lower power and price than their parent's laser. The remaining third intended to develop or search for a way to develop a novel variant of their parent's laser. For the most part, these are rather modest strategies that would not initially pose much threat to the parents,[15] which perhaps explains why we found only two instances of parents suing their spinoffs for infringement of their technology (as indicated by the S code). Consistent with Hypothesis 1, the initial strategies of the 30 or so spinoffs also suggest a very narrow focus in the same general domains as their parents rather than the new niches conjectured by Garvin [1983].

The total number of years of production of the parents is indicative of the types of firms that spawned spinoffs. Some of the parents were either acquired by other laser producers or entered later and were still producing in 1994, making it difficult to use their longevity to gauge their success. To abstract from this, we focus only on firms that began producing lasers before 1976 and were not acquired, which means they could have survived 20 or more years. There were 143 entrants that satisfied these criteria, and 25 or 17.5% survived 20 or more years. In contrast, there were 53 spinoffs that had parents

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[15] Other studies of technical startups have also found that startups began with modest strategies (Braden [1977, pp. 27-29], Roberts [1991, pp. 166-168]).

satisfying these criteria, and 32 or 60% of them survived 20 or more years. Thus, the parents were unusually long-lived, suggesting they were much more successful than the average firm, as predicted (Hypothesis 6).

The timing of the spinoffs among the 32 long-lived parents is revealing about how the likelihood of spinoffs varied with the number of years the parent produced the spinoff's initial laser. The most common five-year production period for a spinoff was when the parent produced the spinoff's laser between 11 and 15 years—10 of the 32 spinoffs occurred in this time period. Moreover, only two of the spinoffs occurred after the parent produced the spinoff's initial laser for over 20 years. Thus, consistent with the speculation in Hypothesis 6, these patterns suggest laser middle age was the most fertile period for spinoffs.

Further insight about the kinds of firms spawning spinoffs can be gleaned from the firms that spawned multiple spinoffs. Six firms stand out with three or more spinoffs: Spectra Physics (S-P) (6), Coherent (5), Hughes (5), Martin Marietta (4), GTE/Sylvania (3), and RCA (3). Apart from Martin Marietta, the other five firms are among the most successful and long-lived in the industry.[16] As predicted (Hypothesis 5), they are also among the most diversified—S-P and Coherent are the only two firms that produced lasers in all nine categories, and the other four produced lasers in 8, 4, 7, and 6 categories respectively. These are striking figures considering that only 2% of the firms (9 in total) produced lasers in 7 or more categories.[17]

The timing of the spinoffs relative to the time pattern of the nonspinoff entrants in Figures 1-7 is indicative of the effect of market conditions on spinoffs. These seven laser types appear to fall into two categories. The first includes solid state, semiconductor, dye, and excimer lasers. Spinoffs in these lasers seem almost uniformly distributed over time, with perhaps a modestly greater number when there were more producers toward the end of the periods. There is certainly no sign of a rise in the number of spinoffs when

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[16] While Martin Marietta was not long-lived as a commercial laser producer, its many spinoffs may reflect its long involvement as a military supplier.

[17] These same six firms also accounted for all but one of the eight individuals that founded more than one laser startup.

nonspinoff entry surged, consistent with the model (Hypothesis 7). The other category, which includes HeNe, ion, and CO2, is distinctive in that spinoffs stopped entirely after a certain point, which encompasses the last ten years or so of HeNe and ion and the last five years for CO2. HeNe and ion are noteworthy because they are the lasers that advanced furthest along the plc, supporting the idea that the nature of firm know-how influences the likelihood of spinoffs (Hypothesis 4). CO2 sustained a sharp decline in the number of producers in its last five years due to competition from solid-state lasers, suggesting a distinctive responsiveness of spinoffs to adverse conditions, consistent with the model (Hypothesis 7).

The codes for laser (A) and nonlaser (N) acquisitions can be used to gauge the potential effect of acquisitions on spinoffs. Nine spinoffs occurred within three years of the parent being acquired by another laser firm and eight occurred within three years of the parent being acquired by a nonlaser firm. This suggests that acquisitions of any kind may have played a role in spinoffs, which is supported by testimony from two founders in retrospective articles on their firms (Laser Focus [1987, p. 82], Olsen [1993]) One of these founders (Olsen [1993]) noted how his spinoff was motivated by anticipation of its parent changing its strategy after being acquired, providing an opportunity for the spinoff in its parent's pre-acquisition market, as predicted by the model (Hypothesis 8). Another type of control change akin to an acquisition is a firm exiting production of a particular laser. There were a number of instances of spinoffs following such exits, and in the statistical analysis we explore this further.

Regarding the effect of agglomerations on spinoffs, the regions in which the parents were located point to one region as being particularly fertile for spinoffs, region 9, which is basically Silicon Valley. Twenty-three spinoffs had parents in Silicon Valley, and in 20 of the 23 cases the spinoff located there as well, with a nonnegligible number drawing on local firms for key employees and at times other founders. The 23 spinoffs with parents in Silicon Valley constitute 29% of all the spinoffs whereas only 15% of the laser firms were located in Silicon Valley. While this is suggestive of a role for agglomerations in the spinoff process, consistent with the model (Hypothesis 9), it may simply reflect the large number of spinoffs of the two industry leaders, S-P and Coherent, both of which were located in Silicon Valley. We will sort this out in the statistical analysis.

The last issue we consider is the background of the parents. Brittain and Freeman found that diversified firms in the semiconductor industry had less spinoffs than semiconductor specialists. The figures indicate that parents of 24 (29%) of the spinoffs were themselves spinoffs, whereas spinoffs constitute only 17% of all laser producers. Spinoffs were generally not diversified beyond lasers, and thus this pattern accords with Brittain and Freeman's findings. A large number of parents, however, were diversified electronics and chemical producers, such as Hughes, RCA, GTE/Sylvania, United Technologies, Honeywell, Raytheon, Allied, and Amoco. The model predicts that the background of firms should have no effect on their number of spinoffs unless it affects the amount of knowledge generated within the firm or the accessibility of the knowledge to employees (Hypothesis 10). We shall explore this further in the statistical analysis.

In summary, the quantitative and qualitative evidence concerning the spinoffs and their parents seems quite consistent with the model. We now turn to the statistical analysis to conduct a more formal test of the model.

VI. Statistical Analysis

We estimate three logits concerning the factors that influenced firms to spawn spinoffs.

In the first logit, the dependent variable is P_i, the probability of firm i spawning a spinoff at any time, and there is one observation for each of the 465 laser producers. This logit examines the factors influencing whether a firm was a parent and abstracts from the number, type, and timing of the firms' spinoffs. The explanatory variables included: the total number of years the firm produced lasers (i.e., the difference between its exit and entry year); the sum of the number of years the firm produced each of the nine categories of lasers; dummies for the preentry background of the firm (preexisting and 4-7 years old at entry, preexisting and over eight years old at entry, spinoff, startup from a university/government lab, startup from another industry, startup with unknown origins); the number of patents in the five years prior to entry (0, 1-9, 10 or more) and a dummy for production of a product in SIC36 in the three years prior to entry for preexisting firms;[18] dummies for exit by acquisition and whether ever acquired by a nonlaser firm; four dummies for location in each of the densely populated regions in the U.S. (Northern California, Southern California, metro NY and metro Boston); and dummies for production for each of the nine categories of lasers.

In the final specification, we included only variables whose coefficient estimates were significantly different from zero at the .05 level (one-tailed if appropriate) in this logit or either of the next two. Their coefficient estimates and standard errors (with the exception of those for the laser type dummies, which are not reported for any of the logits) are reported in the left panel of Table 1. As expected, the total number of years of production of lasers, Tyrs, has a strong, positive effect on the probability of a firm being a parent, confirming that longer-lived firms were more likely to spawn spinoffs. The coefficient estimate for Tyrs implies that for each additional year of production, the odds ratio of spawning a spinoff (i.e., the probability of spawning a spinoff divided by the probability of not spawning a spinoff) is $e^{.107}$=1.1 times greater. We added squared and cubed values of this variable, but their coefficient estimates were insignificant. We also added the sum of the years of production of all lasers to the equation and also used it in place of the total years of production. On its own, its coefficient estimate was significant but it performed worse than the total years of production, and when included with the total years of production its coefficient estimate was insignificant while the coefficient estimate of years of production remained significant. Thus, whether a firm was a parent appears to have been primarily related to its total years in the industry, which is a conventional measure of success. We probe this further in the next two logits.

Regarding the pre-entry background variables, the only one with a significant coefficient estimate was the dummy for being a preexisting firm and having ten or more patents, Pat10+. This increases the odds ratio by a factor of $e^{2.262} = 9.6$. Preexisting firms with 10+ patents in the five years prior to entry were primarily diversified electronics and chemical firms. These firms survived longer in the industry (Sleeper [1998]), quite possibly because they had more technical skills to draw upon to compete in lasers. Thus,

[18] These two variables were included along with the other firm background variables because they were predictive of the length of time firms produced lasers (Sleeper [1998]).

one interpretation of this variable is that it is a proxy for the amount of knowledge employees had to draw upon to start their own firms. A related possibility is that many of these firms worked for the military in the early (and later) years of the industry and at times were reluctant to commercialize their findings, providing opportunities for their employees to start their own firms.[19] This would affect the prospective market for a spinoff. Both factors are consistent with the model. To the extent that the preexisting firms with 10 or more patents were highly diversified, which they were, these findings are at odds with Brittain and Freeman's findings concerning the spinoffs spawned by semiconductor firms. We explore this further in the third logit.

The coefficient estimate of the laser acquisition dummy, Lacq, is significant at the .10 level (one-tailed) and the coefficient of the nonlaser acquisition dummy, Nlacq, is signficant at the .01 level (one-tailed). They imply that firms acquired by other laser firms had a 2.3 greater odds ratio of a spinoff and firms acquired by nonlaser firms had a 4.1 times greater odds ratio. Thus, in contrast to Brittain and Freeman's emphasis on outside control changes, both types of control changes appear to have influenced spinoffs in lasers, although control changes involving an outside firm had a greater effect. None of the regional dummy variables had a significant coefficient estimate. The largest estimate is for the Silicon Valley dummy, Sval, which is reported because of the role it played in the next two logits.

In the second logit, we disaggregate by type of laser. The dependent variable is P_{ik}, the probability of firm i spawning one or more spinoffs initially producing laser k, where k = 1,2,…, 9 corresponds to the nine types of lasers. Each producer is viewed as a potential parent of nine different types of spinoffs, and so there are nine observations for each firm or 4,185 total observations. This logit treats the probability of a firm spawning a spinoff in one laser type as independent of the probability of it spawning a spinoff in any other laser type, conditional on the explanatory variables.

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[19] One documented instance of this is when three scientists at Martin Marietta's Orlando Aerospace Division started their own firm to produce an argon ion laser after Martin Marietta declined to commercialize its ion work for the military (Bromberg [1991, p. 171]).

We can now explore how the probability of a firm spawning a spinoff initially producing a particular laser, denoted generically as laser k, is influenced by the firm's experience producing laser k versus all other lasers. We do this by adding to the specification of logit 1 two variables: a dummy equal to 1 if firm i produced laser k, Prodk, and the total number of years firm i produced laser k, Tyrsk (equal to 0 for firms that did not produce laser k). The other variables are the same as logit 1 except that the dummies for each laser type now distinguish the various laser categories rather than reflect which lasers firm i produced (i.e., they allow for market fixed effects).

The coefficient estimates and standard errors for the variables in the final specification are presented in the middle panel of Table 1. The coefficient estimates for Prodk and Yrsk are both significant at the .01 level and large. The odds ratio is 12 times greater for producers of laser k and 1.1 greater still for each year of production of laser k. Quadratic and cubic terms for Yrsk were not significant. The coefficient estimate for the total years of production of all lasers is not reported because it was trivial and insignificant. We also used the sum of the years of production of all lasers other than laser k in place of and with the total years of production, but its coefficient estimate was also trivial and insignificant. These results provide strong support for spinoffs exploiting targeted knowledge of the parent pertaining to the laser initially produced by the spinoff. Among the other variables, the main change is that the coefficient estimate for location in Northern California (around Silicon Valley) is now significant (at the .05 level, one-tailed), suggesting that being located in the most densely populated region increased the probability of a firm spawning a spinoff.[20]

In the third logit, we further disaggregate by year. Each firm is now considered a potential parent of a spinoff initially producing laser k in each year beginning with either

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[20] Firms with multiple spinoffs initially producing different lasers have more influence on the coefficient estimates of this logit than the first because they account for a greater fraction of the observations corresponding to spinoffs. The two most prominent of these multiple spinoff firms, S-P and Coherent, are both located in Silicon Valley, which may explain the greater influence of Silicon Valley in this logit (and the next) than in logit 1.

its first year of laser production or the first year laser k was produced, whichever was later. We allow for it to be a parent through 1994, the last year of our sample, as its employees might have started their own firm even after the firm ceased producing lasers (or laser k). The dependent variable of this logit is P_{ikt}, where t refers to years, and in total there are 58,893 observations. This logit treats firms' spinoff probabilities (conditional on the explanatory variables) as not only independent across markets but also across years in the same market. We shall return to consider the adequacy of this stance.

We can now probe how experience in laser k and general experience affected not only the incidence but also the timing of a spinoff initially producing laser k. For firms that produced laser k, three time period dummies are included. The first, Currk, equals 1 for years t in which firm i was still producing laser k. The other two, ≤5yrsk and >5yrsk, are equal to 1 respectively for years t within 5 years and over 5 years after firm i ceased producing laser k (all three dummies equal 0 if firm i never produced laser k). If a firm produced laser k in year t, we also include the number of years it produced laser k through year t, Yrsk, and the square of this value, Yrsk2. This allows us to test whether the most fertile spinoff time in the firm's experience in producing laser k was in its middle years, as suggested in the model and the prior section. For firms that produced laser k, we also added a separate variable equal to the <u>total</u> number of years it produced laser k, Tyrsk, as a proxy for its success in producing laser k.[21] We probe the role of

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[21] This measure fails to take account of the effect of censoring (producing laser k in 1994 or when acquired by another laser firm), which artificially limits the total number of years of production of laser k. To address this, we added a dummy for censored firms. If the additional number of years they would have produced laser k is independent of their past years of production of laser k, the coefficient on the dummy should equal the coefficient on the total number of years laser k was produced times the expected additional years of production of laser k. However, the coefficient estimate for the dummy was trivial and insignificant. This may reflect that censored firms with a longer history of production of laser k would be expected to produce it for more additional years

general experience by also using three time dummies. The first, Currp, equals 1 for years t in which the firm was still producing lasers. The second, ≤5yrsp, equals 1 for years t within five years of the firm exiting laser production. The third variable, over five years since exiting lasers, is omitted for identification and serves as the reference period. For firms still producing lasers in year t, we also include the number of years the firm produced lasers through year t, Yrsp, as a measure of its total experience.

We include Sval and Pat10+, as in the prior two logits, and also the acquisition variables, but we now restrict the acquisition dummies to equal 1 only in years t up to two years before and five years after the acquisition. This allows for the effects of each type of acquisition, denoted now as Lacq52 and Nlacq52, to anticipate the acquisitions by up to two years and to occur within five years of the acquisitions. In order to probe our two interpretations of how Pat10+ operated, we divided it into two variables, P10+k and P10+nk, to allow it to affect the probability of a spinoff separately for firms that were and were not producers of laser k respectively.

Last, we included a set of variables to probe how market conditions affected spinoffs. We constructed a variable measuring the rate of nonspinoff entry into market k in year t to probe how spinoffs are conditioned by the factors generally affecting nonspinoff entry. This variable equals the number of nonspinoff entrants in market k in year t divided by the number of firms producing laser k in year t-1 plus two lagged values of this variable (for smoothing purposes), expressed as a deviation from the mean value of this variable for market k across all years. In order to avoid very large values of this variable in the early years of markets when the number of producers is very small, we set it equal to zero in the first seven years of a market. To compensate, we separately included a dummy variable equal to 1 for years t in the first seven years of market k, First7k. This also allows spinoffs to capitalize on the early experience of their employers that was not reflected in their commercial production but is reflected in the P codes in the figures, which tend to be concentrated in the early years of the various types of lasers. We divided the entry variable according to whether it was positive, Enk+, or negative, Enk-,

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than firms with a shorter history of production k and/or acquired firms. Both possibilities make the need for a censoring correction less compelling.

to test for an asymmetric effect of favorable and adverse market conditions on spinoffs, as predicted by the model. We entered linear time trends for years since the beginning of HeNe and ion production, THeNe and TIon, to test for a decline in the probability of spinoffs over time in these markets due to progressing further along the plc.[22] We also included fixed effects for the separate laser categories.

The coefficient estimates and standard errors are presented in the right panel of Table 1. All three period dummies for the production of laser k are positive and significant (the last at the .05 level, one-tailed). The coefficient estimate for ≤5yrsk is not much greater than the coefficient estimate for Currk, which calibrates the probability of a firm spawning a spinoff initially producing laser k when it first began producing laser k. This suggests that the period immediately after a firm ceases production of laser k is not a particularly fertile period for spawning spinoffs initially producing laser k. The coefficient estimate for >5yrsk is smaller than the other two but still substantial. It implies that the effect of production of laser k on the rate of spinoffs initially producing laser k declines over time after production of laser k ceases but persists for many years. The coefficient estimates of the linear and quadratic terms are positive and negative respectively and both are significant at the .01 level. The estimates imply that the probability of a spinoff initially producing laser k initially rises and peaks when the firm has approximately 14 years of experience producing laser k, after which it declines. Its odds ratio is then 11.4 times greater than when it started producing laser k, and it declines back to its initial value after 28 years of experience, which very few firms attained in any laser.[23] The coefficient of the total years of production of laser k is positive but its standard error is sufficiently large that it marginally falls short of significance at the .10 level (one-tailed). It suggests that the firm's success producing laser k may increase the

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[22] We also entered a linear time trend for spinoffs in all laser types, but its effect was small and insignificant and thus is not reported.

[23] It is still greater at this point than firms that never produced laser k, and thus additional years of experience in laser k continue to increase the firm's cumulative probability of spinoffs initially producing laser k.

probability of it spawning a spinoff initially producing laser k in every year, but the crudeness of the measure limits the confidence one can have in such an inference.

The variables for general experience provide insight into how general experience can affect the probability of a spinoff. Similar to the first two logits, the coefficient on years of (general) experience, Yrsp, is trivial and insignificant, suggesting again that spinoffs draw on targeted but not general knowledge of their parents. The period dummies indicate that the probability of a firm spawning a spinoff initially producing laser k is similar for both current producers and firms within five years of leaving the industry, but falls after a firm has not produced for over five years. This may reflect that after five years, employees of the firm that have not started their own firm either have found employment with another laser firm or have left the industry, diminishing the chance of them starting a laser spinoff (attributed to their initial employer). This appears to be the only way general experience enters into the spinoff process.

The four firm variables continue to have significant effects. Both acquisition variables, whose effects are now limited to short intervals around the acquisitions, have significant coefficient estimates, although the coefficient estimate for nonlaser acquisitions is smaller than in logit 2 and is significant at only the .10 level (one-tailed). The effect of locating in Silicon Valley is virtually the same as logit 2 and is significant at the .05 level. The P10+ variable has a much stronger estimated effect for nonproducers of laser k (P10+nk), but it has a significant effect for producers of laser k (P10+k) as well. Its significant effect for both groups of producers supports the interpretation of P10+ as a proxy for general knowledge employees have to draw upon to start any kind of spinoff. Its greater effect for nonproducers of laser k suggests it may also be a proxy for diversified, technically-oriented firms that worked for the military. These firms were sometimes reluctant to commercialize the knowledge they generated, providing greater opportunities for spinoffs in laser types they did not commercially produce. This interpretation would be quite different from Brittain and Freeman’s finding of a lower incidence of spinoffs in diversified semiconductor producers.

The final set of estimates pertain to the market variables, and these are all as predicted. The coefficient estimate for First7k is positive and significant, indicating a higher spinoff rate in the early years of markets than expected based on firms’ limited experiences in the markets. The coefficient estimate for Enk+ is positive but small and insignificant whereas the coefficient estimate for Enk- is positive, large, and significant. This supports the predicted asymmetric effect of market conditions on the spinoff rate. The HeNe and ion time trends are both negative, with the ion coefficient estimate significant at the .05 level (one-tailed) and the HeNe nearly significant at the .10 level (one-tailed). This suggests a falloff in the spinoff rate in both markets that is not accounted for by any of the measured factors.

We consider one last issue concerning the adequacy of assuming that the annual probability of a firm spawning a spinoff initially producing a particular laser is independent over time. This requires that we measure all the persistent firm factors bearing on spinoffs in each market and also that the act of employees leaving the firm to start a spinoff producing a particular type of laser does not affect the inclination of other employees to start a similar spinoff. To probe this, we summed the predicted annual probabilities for each firm across all laser markets and years to get a predicted total number of spinoffs for each firm. In Table 2 we present the predicted number of spinoffs for the six firms with three or more spinoffs in the top panel and the average predicted number of spinoffs for groups of firms with 0-6 spinoffs in the bottom panel. The top panel indicates that the model does quite a good job of predicting the spinoffs of the top six firms with the exception of Martin Marietta, which accords with our analysis in the prior section. In fact, it predicts all but Martin Marietta would be ranked in the top six based on the predicted number of spinoffs, and mispredicts only Raytheon in the top six (Raytheon had only one spinoff but was predicted to have the second most spinoffs of any firm, 4.61). The bottom panel indicates the model also does a good job on average of accounting for why some groups of firms had more spinoffs than others. It predicts a monotonically increasing number of spinoffs as the actual number of spinoffs increased across groups except for Martin Marietta's group of 1 with four spinoffs. It tends to underpredict the number of spinoffs of the groups with a positive number of spinoffs, but this would be expected given that the firms with no spinoffs will always be predicted to have some spinoffs.

VII. Discussion

The statistical findings and qualitative evidence presented earlier provide strong support for the various implications of the model.

Almost invariably, spinoffs initially produced lasers their parents produced, and they appear to have drawn only on their parents' experience in their initial laser and not their parents' general experience. This suggests that spinoffs exploited targeted knowledge from their parents. At the same time, spinoffs appear to have differentiated their initial lasers from their parents' related lasers and initially serviced narrow, targeted niches. This enabled them to avoid retaliation from their parents and also not compromise the viability of the market for their parents' related lasers.

The greater number of spinoffs spawned by more successful firms suggests that spinoffs were more likely in environments in which employees had more knowledge to draw upon. More successful firms produced a greater number of laser types, and each appears to have been an independent source of information for spinoffs to draw upon. Furthermore, for each type of laser that firms produced, the more successful firms produced them longer. This appears to have increased their chance of spawning a spinoff in every year, which we interpret as an indication of the greater knowledge they had for spinoffs to exploit. It also increased their chances of reaching the most fertile years of experience for spinoffs to occur.

Within each laser submarket, spinoffs were responsive to adverse but not favorable conditions for entry. It appears they were driven less by market conditions than the long-term fates of their parents. In two submarkets that had progressed furthest along the plc, spinoffs dried up entirely, suggesting a change in the kind of information firms generated that compromised the knowledge available for spinoffs to exploit.

Acquisitions of firms increased the chance of spinoffs, possibly by providing a bigger market for spinoffs to capture. Preexisting firms with a greater technical orientation as reflected in their prior patenting had more spinoffs. This appears to have been related both to the greater knowledge they generated for spinoffs to exploit and their reluctance at times to commercialize work they performed for the military, providing a bigger market for their spinoffs to capture. Firms located in Northern California around Silicon Valley had more spinoffs, which may well have been due to the greater ability to form founding and initial management teams from the wealth of laser and nonlaser talent in Silicon Valley.

Interpreted through the lens of the model, these findings not only have implications about spinoffs but also for evolution and organizational behavior, the determinants of entry and the evolution of market structure, and technological change and industry performance. We began the paper by discussing the parallels that have usefully been drawn between natural evolution and industrial competition, particularly using the metaphors of variation and selection so central to evolutionary theories. Our findings suggest that the less-used evolutionary notions of birth and heredity may have comparably useful roles in understanding spinoffs. Spinoffs appear to closely resemble their parents, inheriting from them their initial products and market focus. But just as organisms are not clones of any of their parents, spinoffs also differed from their parents. As the model emphasizes, and perhaps similar to humans, spinoffs need to differentiate themselves from their parents to succeed on their own. Pushing the evolutionary metaphor further, more fit members of the species (industry) have higher rates of reproduction, which as we discuss below bears on the fitness of the entire species.

Perhaps the most significant implication of harnessing the notions of birth and heredity to spinoffs is that it strengthens the idea of organizations with distinctive, and limited, capabilities. This is a long-standing theme in the literatures of business strategy and organizations. Our findings provide a clearer picture of the origin of these capabilities for one class of organizations, spinoffs. They also provide insights into the limits of organizations. Judging from the similarities between spinoffs and their parents, organizations need targeted technical and market information to be able to compete in particular markets, and this information is difficult to come by. This suggests that in developing a business strategy, organizations, especially new organizations, need to think carefully about the information they have access to and how they can profit from it.[24] It also suggests that conducting the kind of industry analysis advocated by Porter [1980] to find attractive venues to enter and strategies to pursue will be of limited value to startups.

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[24] Holbrook et al. [2000] reach the same conclusion about preexisting firms as well as startups in a detailed examination of four early entrants into the semiconductor industry.

Our findings regarding the initial strategies of spinoffs resonate with Bhide's [2000, pp. 29-68] findings about the initial strategies of successful startups. Both started out with limited knowledge and modest strategies. The initial success of Bhide's startups depended on their ability to exploit unexpected opportunities. Their continued success depended on their ability to transform themselves as they grew to take advantage of their greater size, which enabled them to take on more capital intensive projects with more predictable outcomes. To the extent this resulted in them generating knowledge that became more embodied in physical than human capital, it may help explain our findings concerning the effect of a firm's experience on its rate of spinoffs. Inexperienced firms would not have much knowledge to draw upon, whereas successful firms presumably would have more knowledge for spinoffs to exploit. But if successful firms changed their strategy as they grew and aged, causing the character of their knowledge to become more embodied in physical capital, then employees might have more difficulty accessing the firm's key knowledge. In effect, organizations would go through a comparable evolution to the plc operating at the market level, which could explain the nonmonotonic effect of experience on the spinoff probability that we found. This deserves further exploration.

Our findings also provide insights into the entry process. The conventional economic view of entry is that it is a response to incumbents earning high profits. However, Geroski [1995] notes that this view has been quite limited in its ability to explain variations in entry across markets and within markets over time. These limitations are palpable for our laser spinoffs, which constituted over 15% of the entrants into the laser industry. They do not appear to have been at all responsive to the factors favoring nonspinoff entry. Our findings suggest why—spinoffs are tied to the experiences of incumbent producers and not the prospects for new producers. They enter when their parents generate the information they need to exploit, which tends to be when their parents reach laser middle age. The turnover among laser producers has contributed to a fairly steady stream of new firms and thus new candidates for laser middle age, contributing to a steady stream of spinoffs. Their timing is determined principally by their parents and not the market, although it is not hard to envision how they could be discouraged by adverse developments, as we found.

Our findings regarding the decline in the spinoff rate in the HeNe and ion submarkets also suggest how distinctive market conditions not directly related to the profitability of incumbents could influence entry. To the extent markets evolve according to the plc, opportunities for spinoff entry may dry up, causing the overall rate of entry to decline. This can have far reaching implications regarding an industry's market structure. In lasers, the steady stream of spinoffs has no doubt contributed to the turnover in producers and limited the concentration of producers. Should more submarkets evolve according to the plc with greater attention devoted to improving the production process, however, it could lead to less spinoffs and greater market concentration (cf. Klepper [1996, 1999]). Indeed, a distinguishing feature of the four industries studied by Klepper and Simons [1997] that experienced sharp shakeouts and evolved to be oligopolies is that producers devoted great effort to improving the production process. Turned around, this implies that an important reason the laser industry has not become very concentrated is that significant opportunities to improve the production process have so far been limited to only a few lasers. Why this is so deserves further investigation.

Finally, our findings have implications about the private and social consequences of spinoffs, particularly as they bear on technological change. Spinoffs are often characterized as exploiting discoveries their founders worked on in their prior employer (cf. Anton and Yao [1995]). Many parents perceive spinoffs as predators that steal their ideas and innovations. Intel epitomizes this attitude. It is willing to go to great lengths to discourage spinoffs, including harrassing them with legal suits (Jackson [1998, pp. 211-338]). Not only does this result in socially wasteful expenditures, but the prospect of spinoffs could even discourage firms from undertaking innovations that employees could appropriate within their own firms. Alternatively, much of the empirical scholarship on spinoffs is preoccupied with their prowess at innovation. They are often perceived as overcoming the bureaucratic inertia plaguing established companies.

Our model and findings provide some insight into this debate. The model provides a rationale for spinoffs without invoking some kind of bureaucratic inertia plaguing established firms. They have an incentive to pursue ideas that their parents would not because it would cannibalize their market. This is not necessarily socially productive. However, we can use another analogy to natural evolution to understand how spinoffs can be socially beneficial. An organism's behavior is determined not only by its genes but also by its environment. Similarly, once "born," a spinoff's activities will evolve in unpredictable ways. In evolutionary terms, this provides the basis for diversity, which in the context of innovative industries like lasers means diversity in the kind of innovations firms develop. Many evolutionary theories emphasize the importance of diversity. Relatedly, Nelson [1981, 1990] has stressed the critical role diversity plays in the success of capitalism while Cohen and Klepper [1992] and Klepper [1996] theorize about how a decline in diversity can retard an industry's rate of technological change. Interpreted in this light, spinoffs can be quite beneficial socially.

The laser industry provides a forum to evaluate these arguments. While we found instances of spinoffs commercializing ideas that established firms chose not to pursue, we found few instances of spinoffs appropriating the ideas or innovations of their parents. Spinoffs appear to have engaged in a range of activities to differentiate their lasers from those of their parents. Many introduced important innovations over their lifetimes and became very successful. The two leading firms in the industry, Spectra Physics and Coherent, were both spinoffs, and most of the leading U.S. firms that specialized in particular submarkets were spinoffs. Clearly, many of the spinoffs brought distinctive abilities to the industry that enabled them to develop in unanticipated ways and no doubt advanced the industry's rate of technological change. Given the spillovers inherent in innovation, it is not much of a leap to suggest that spinoffs may have conferred considerable social benefits. Drawing yet another analogy to natural evolution, the most fit firms in the industry had a higher rate of spinoff reproduction, which no doubt strengthened the entire laser industry by planting the seeds of diversity and speeding up the replacement of less fit firms with superior performers.

In conclusion, the perspective of spinoffs being descended from their parents provides a useful way of exploiting many of the concepts that have been productively employed in theories of natural evolution. It yields insights into organizational behavior, business strategy, entry and industry evolution, and technological change. Understanding the lineage of not only spinoffs but other types of entrants may yield further insights into an even broader array of important issues concerning industrial competition and technological change.

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Table 1: Coefficient Estimates (Standard Errors) for 3 Logits

Logit 1: Dep. Var.=P_i		Logit 2: Dep. Var. = P_{ik}		Logit 3: Dep. Var. = P_{ikt}	
Variable	Coef. estimate (s.error)	Variable	Coef. Estimate (s.error)	Variable	Coef. Estimate (s.error)
Constant	-4.505	Constant	-8.242	Constant	-11.333
	(0.464)		(0.868)		(1.171)
		Prodk	2.484	Currk	2.263
			(0.488)		(0.703)
Tyrs	0.107	Tyrsk	0.139	≤5yrsk	2.752
	(0.032)		(0.020)		(0.623)
Lacq	0.823	Lacq	0.663	>5yrsk	1.569
	(0.583)		(0.362)		(0.941)
Nlacq	1.409	Nlacq	0.806	Yrsk	0.348
	(0.558)		(0.342)		(0.094)
P10+	2.262	P10+	1.707	Yrsk2	-0.012
	(0.460)		(0.292)		(0.004)
Sval	0.436	Sval	0.594	Tyrsk	0.022
	(0.500)		(0.328)		(0.020)
				Currp	1.311
					(0.893)
				≤5yrsp	1.661
					(0.863)
#obs	465	#obs	4185	Yrsp	0.016
					(0.029)
Logl	-102.489	Logl	-214.288	Lacq52	0.714
					(0.385)
				Nlacq52	0.562
					(0.358)
				P10+k	0.739
					(0.274)
				P10+nk	2.227
					(0.635)
				Sval	0.598
					(0.268)
				First7k	0.802
					(0.389)
				Enk +	0.369
					(0.559)
				Enk -	4.382
					(1.718)
				THeNe	-0.063
					(0.053)
				TIon	-0.1002
					(0.057)
				#obs	58893
				Logl	-437.362

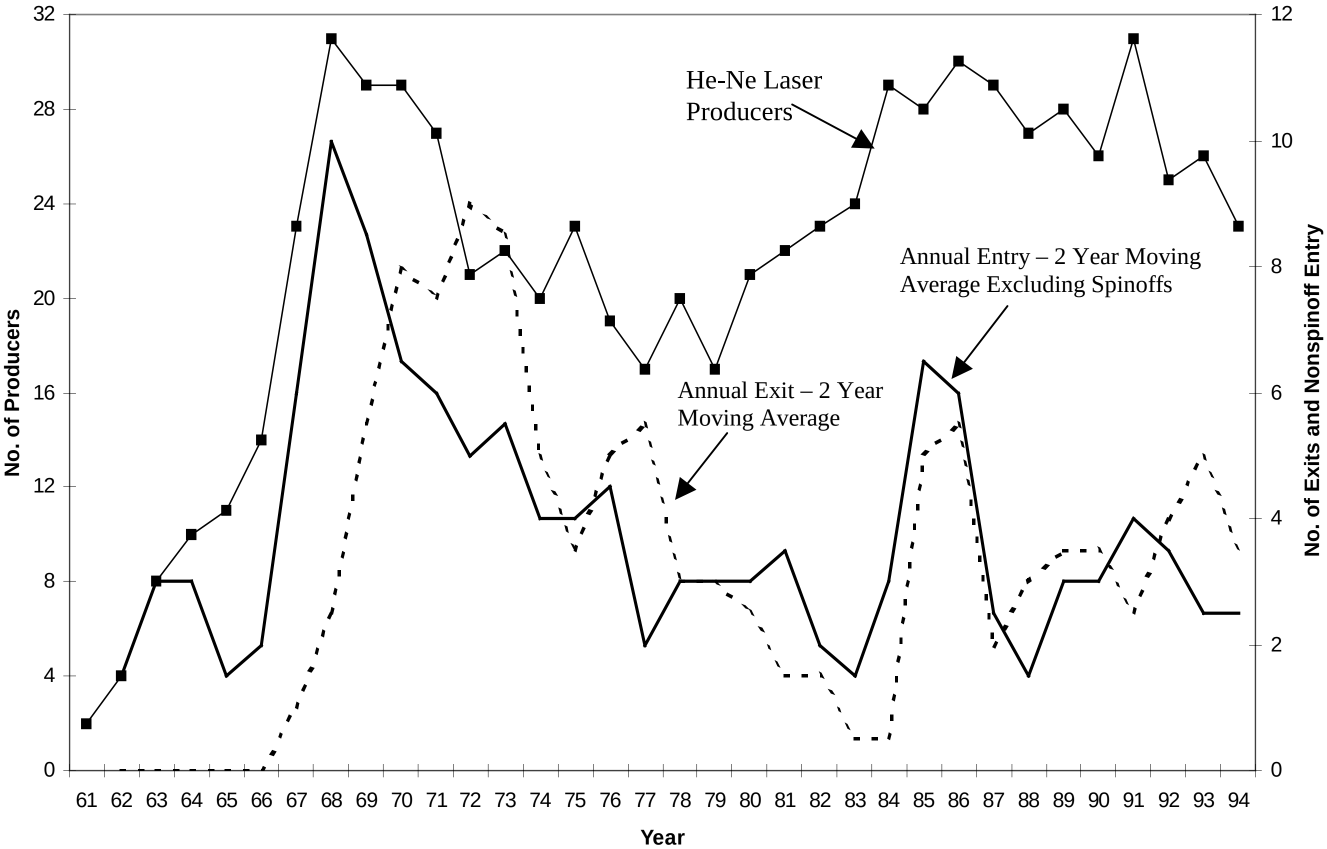
Table 2: Actual and Predicted Number of Spinoffs for Firms with 3 or More Spinoffs

Firm	Number of Spinoffs	Predicted Number of Spinoffs	Predicted Rank
Spectra Physics	6	5.75	1
Hughes	5	3.39	3
Coherent	5	3.20	5
Martin Marietta	4	0.38	20
GTE/Sylvania	3	3.29	4
RCA	3	2.61	6

Average Predicted Number of Spinoffs
For Firms with Different Numbers of Spinoffs

Number of Spinoffs	Number of Firms	Average Predicted Number of Spinoffs
0	413	0.09
1	39	0.47
2	7	0.70
3	2	2.95
4	1	0.38
5	2	3.30
6	1	5.21

Figure 1: Helium-Neon Laser Market



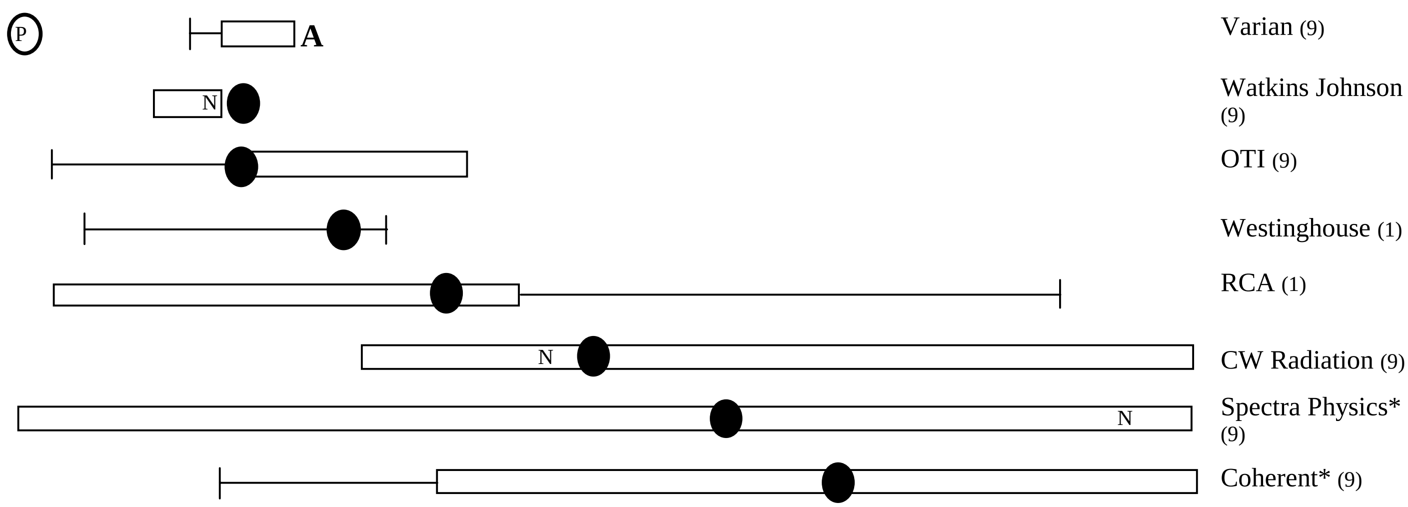


Figure 2: Solid State Laser Market

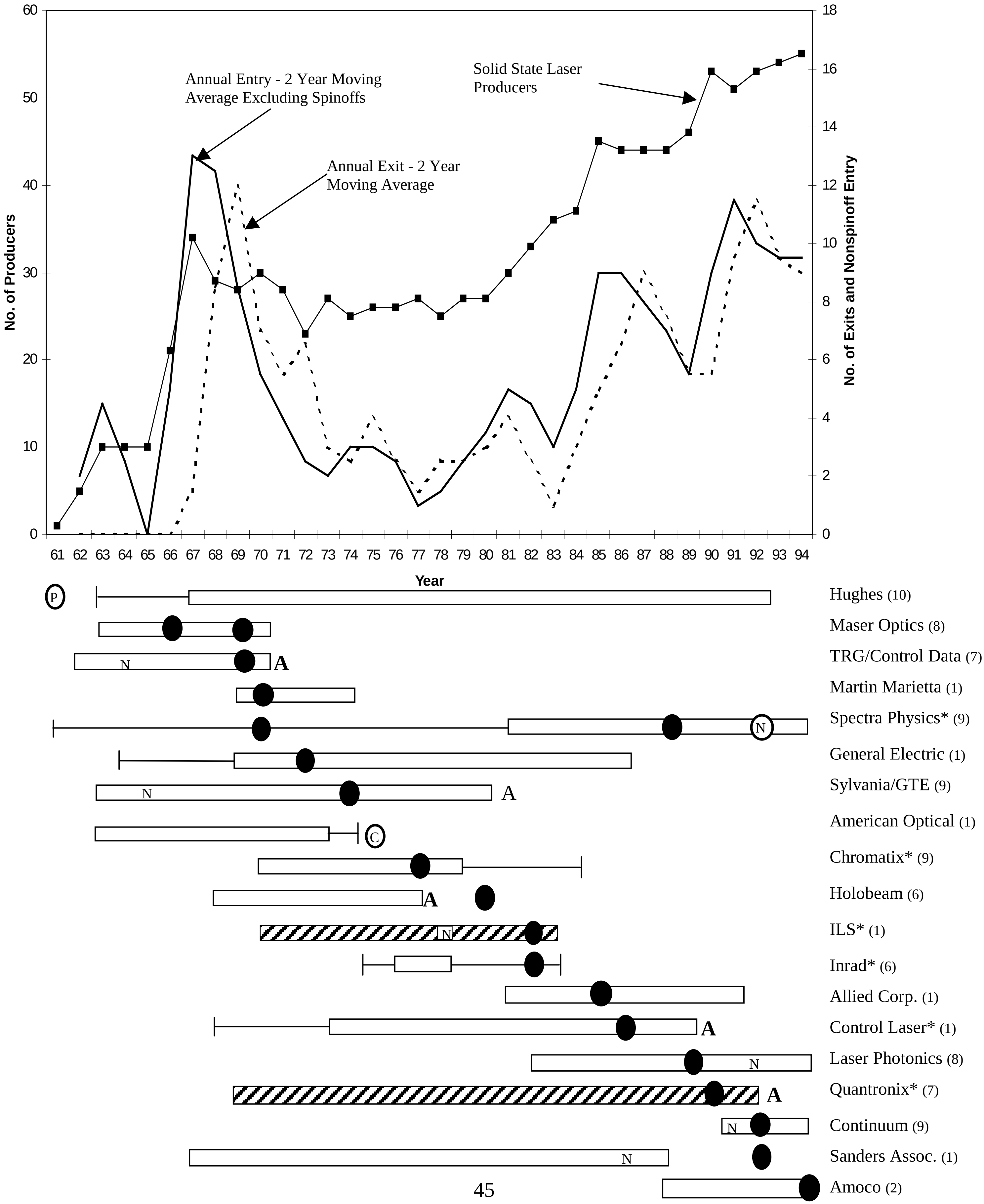


Figure 3: CO2 Laser Market

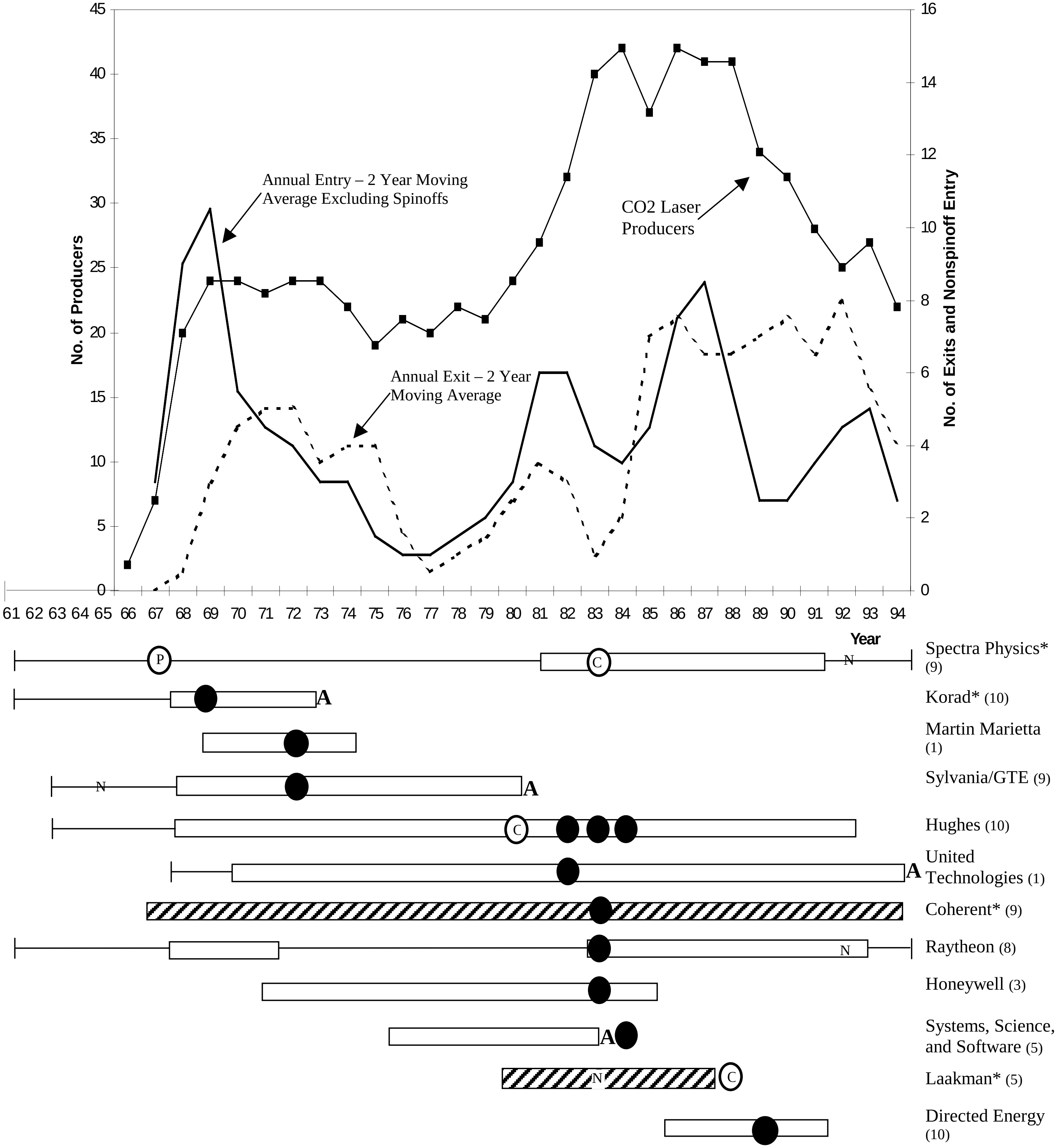


Figure 4: Ion Laser Market

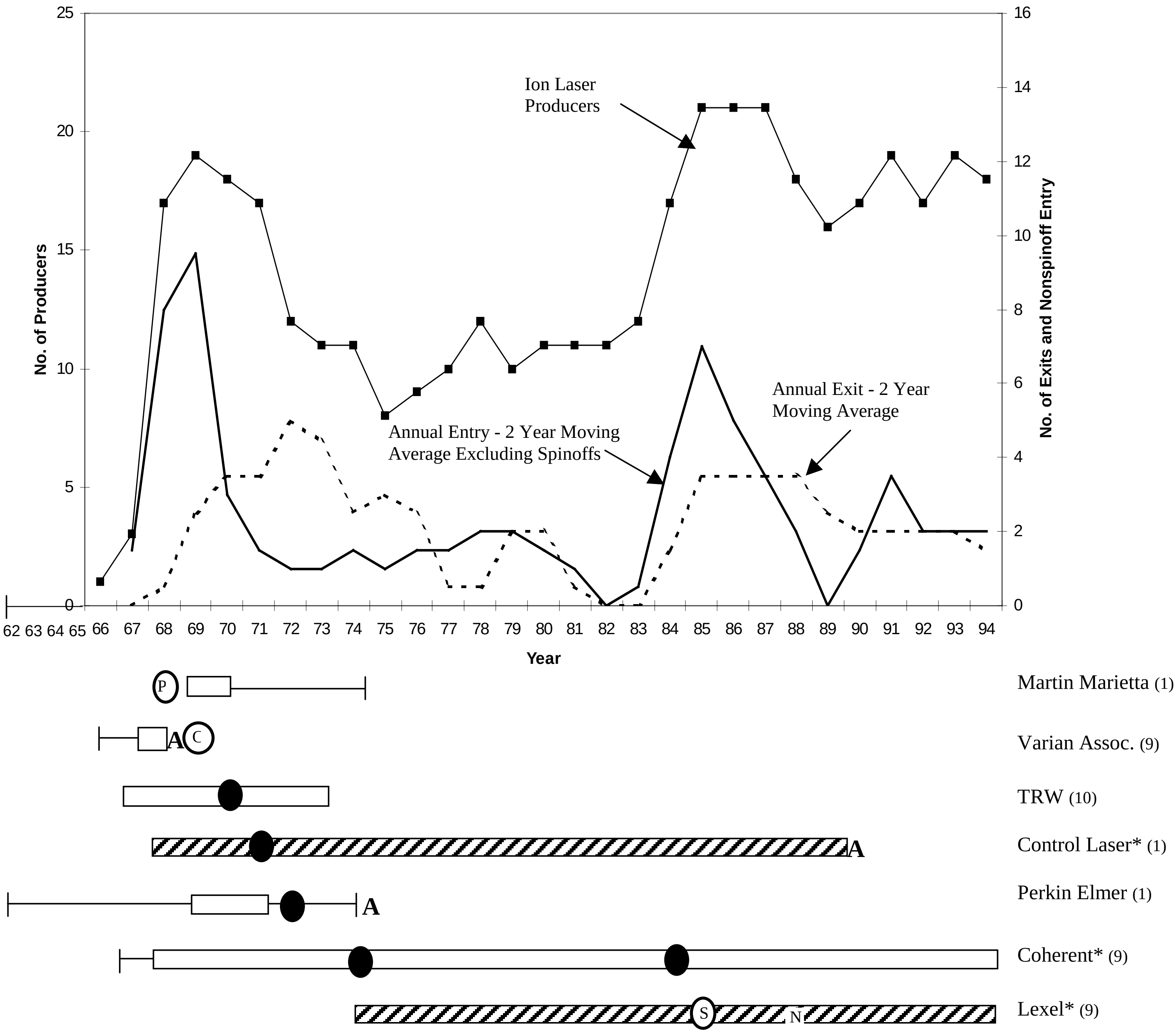


Figure 5: Semiconductor Diode Laser Market

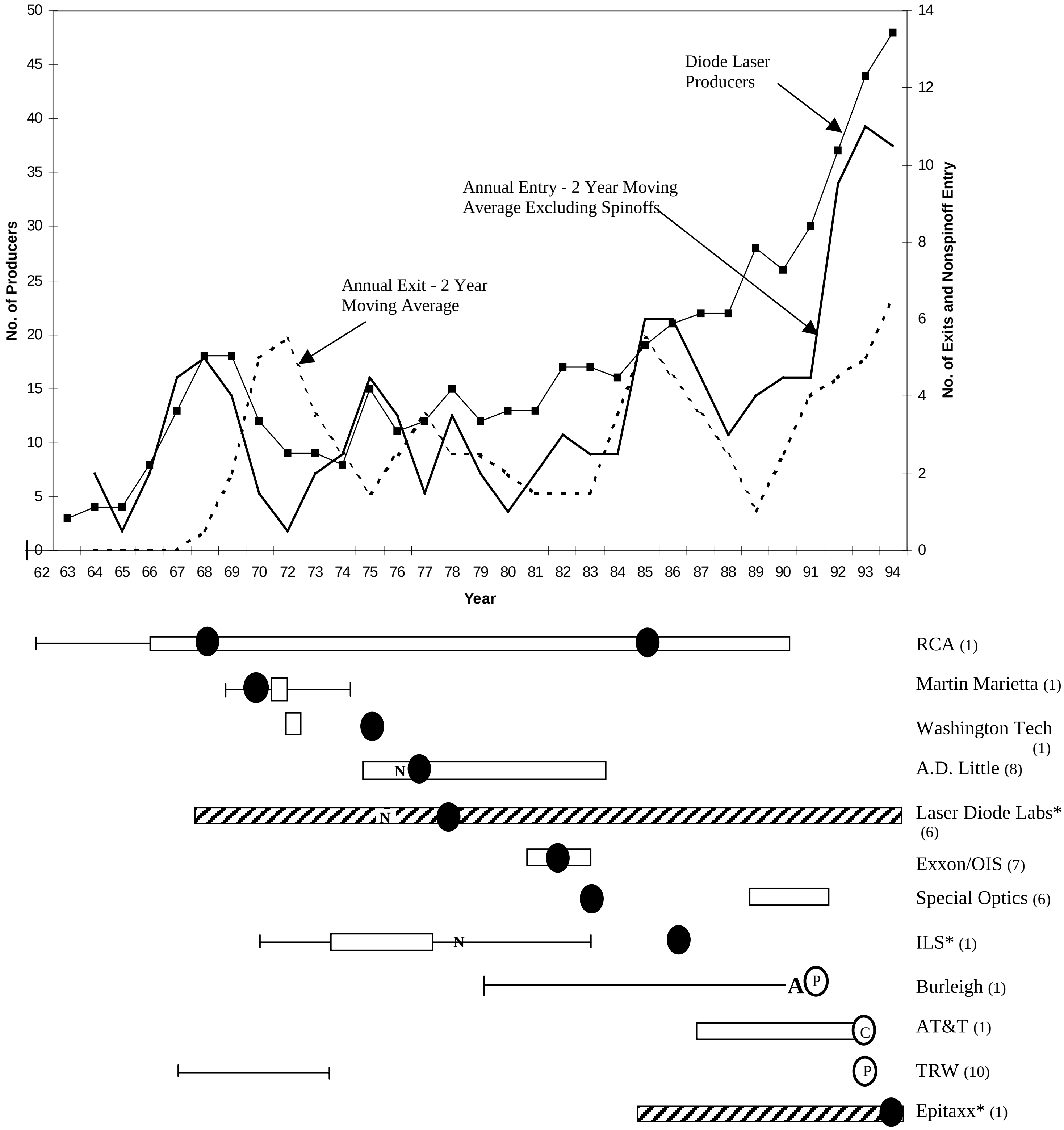


Figure 6: Dye Laser Market

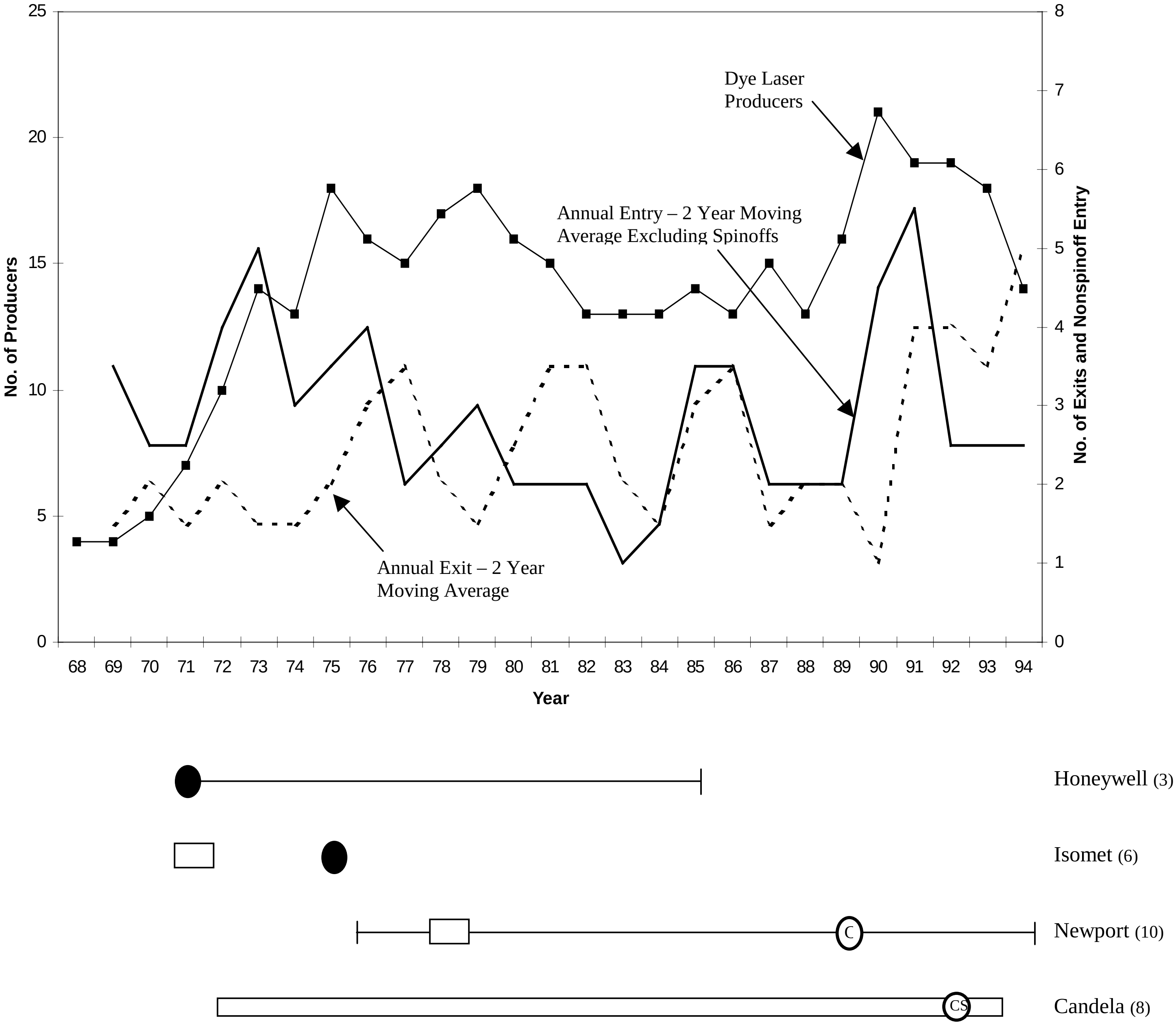


Figure 7: Excimer Laser Market

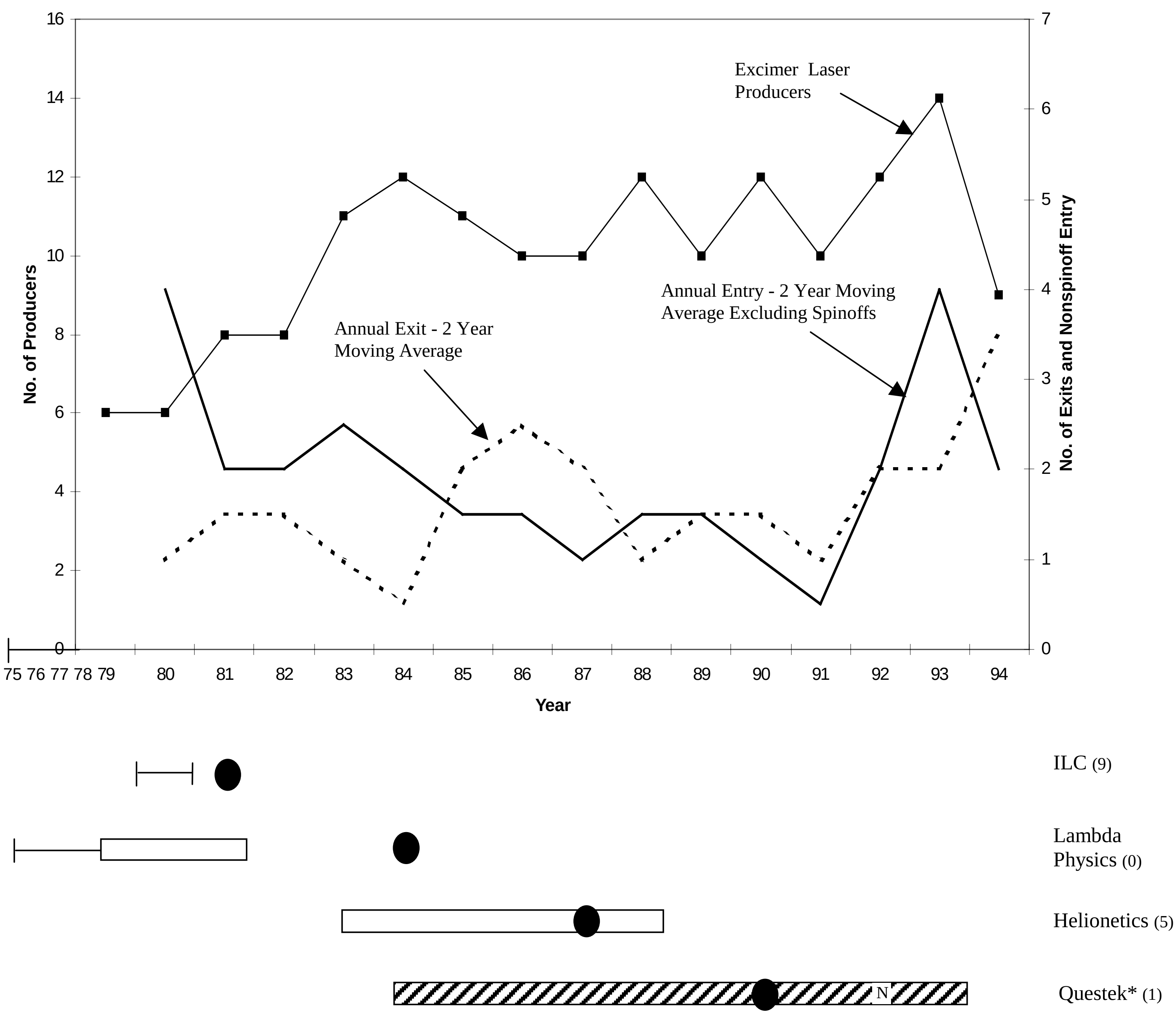


Figure 8: Other Gas Lasers